Multicriterial forest fire risk assessment applicable in Central Europe – Case Study

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***Abstract*— This paper presents results of fire risk assessment for the area of Slovenska Lupca forest management unit, situated in the center of Slovak republic. The fire risk is expressed in terms of one of the risk components - the susceptibility to fire. To assess it, there were performed multicriterial analysis, taking into consideration two basic groups of factors – natural and social. The analysis of fire risk, susceptibility to fire respectively, was automated via its processing in decision making model built in NetWeaver environment. Linking the NetWeaver environment with Ecosystem management decision support system (EMDS), there was obtained the spatial visualisation of assessment results. From the results obtained follows that in case of the Slovenska Lupca forest management unit the majority of the area belongs to the medium high degree of susceptibility to fire (60 %) and almost 40 % of the area belongs even to the high degree of susceptibility to fire.**

***Index Terms*—fire risk, multicriterial analysis, spatial decision support systems, susceptibility.**

I. Introduction

Forest fire can be considered part of the forest ecosystem. Historically, under the influence of lightning or spontaneous ignition originated fires that had more or less destructive impact on forest and human structures (property) situated in those areas. However, there cannot be generally said that forest fire has only a negative effect on forest ecosystems. In some regions, e.g. North America, just forest fires necessitated the formation of herbal and woody communities that use the fire in a competitive fight in their favor and are fully dependent on it. Finally, the man is grateful for the fire just forest fires, which affected its further development.

However, today we understand the forest fires a little differently. In the country altered by anthropogenic activities and largely utilized for the needs of society, a large forest fire is a risk of huge damage to humans. Also the originator of the forest fire has changed. Currently, the most common cause of forest fires is a man alone. Fire arises mainly from inadvertent use of an open fire (burning dry grass, hiking, camping, smoking). According to this background, nowadays, the forest fire is considered harmful anthropogenic factor or a harmful agent of natural origin in our conditions.

To minimize the losses caused by fire is necessary to build efficient and functional system of risk management, where the risk assessment together with planning and realization of effective prevention measures play the key roles.

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The paper presents an approach to fire prevention dealing with problem of fire risk assessment, applying new sophisticated tools, spatial decision support system, to localize the fire threat in space. It is important as from the fire prevention (fire monitoring) as from management of fire suppression activities point of view.

II. Factors influencing the forest fire occurrence

Over the past decade, the number of forest fires in the world is constantly increasing. It is now believed, that annually forest fires damage or even destroy on average 600 000 ha of forest land [1].

In Europe and around the world, the situation regarding the occurrence of fires is getting worse, and the consequences seem to be severe. However, in the current situation several factors create suitable conditions for formation of fires. Among those factors belong natural, climatological and socio-economic factors.

Natural and particular climatic factors usually predetermine the probability of forest fires. Economic measures in forests are other factors influencing the accumulation of fuel in the forest, especially because of the suppression of fire and gradually expanding transit zones between urban areas and the natural environment [2, 3]. Consequently, the distribution of forest fires in the area is determined not only by the climate but also socio-economic factors [4, 5].

In terms of socio-economic factors the greatest importance has urbanization, availability of fire brigades, management in forest and others.

Urbanization because of the departure of the young population from rural areas and agricultural mechanization leads to another problem, and that is the accumulation of fuel [6, 7, 8].

In many cases, the limited availability of volunteers and fire/fighters in rural areas leads to an increase of uncontrolled fires caused by the burning of grassland [8]. These problems are strongly influenced by national policies.

Burning of grasslands on agricultural land is a common practice throughout Eastern Europe in the spring and early summer [9].

In general, at present also in the practice of forest management is preferred shift in management of forest from the production function of the forest to nature conservation and the use of forest for recreational purposes. Recreational use of the forest on the other hand, involves the gradual building of cottages, causing an increase in the transit zones between built-up area and the natural environment that increase the risk of fire, because man and his intentional or

unintentional activity is still the most common cause of fire in the natural environment.

All these factors and processes affect the risk of fire in the general European level, but it also should be noted that in comparison with the Mediterranean countries, in conditions of Central and Eastern Europe, there often lacks a consistent and long-term evidence of the fires, by which it is possible to use statistical and geostatistical methods to calculate the risk of fires [10, 11].

III. Fire risk

The issue of forest fires is addressed globally and has importance also in our conditions, in particular with regard to the impact of ongoing climate change, which is manifested by the extreme weather, which is closely linked to the increased number of forest fires and enlarging their extent, and the consequent need for the protection of persons and property, as well as the environment (in particular with regard to the habitats of national or European importance) against its impact.

In the world there exist several national systems dealing with not only the assessment of the degree of danger of forest fires, but also their constant monitoring. The wildfire danger rating systems have developed the most countries dealing with prevention of fire occurrence, so that the civil protection authorities are able to define the territory with a high probability of fire and to decide on the necessary actions. Most of these systems are based on meteorological data obtained from meteorological stations, e.g. air temperature, humidity, and wind speed.

Probably the most sophisticated system is the Canadian national system for the assessment of the risk of devastating forest fires - Canadian Forest Fire Danger Rating System (CFFDRS). Its integral part is the CWFIS (Canadian Forest Fire Index) - the computer fire management information system, which is used for monitoring the conditions of the fire danger across Canada. This offers daily weather maps with an expression of fire danger (coefficient) on the basis of daily weather conditions, maps, maps of potential fire hot spots (places with a high degree of danger). In addition to maps, it also offers satellite images of distant territories or territories that is necessary to watch due to the danger of fire. A quantitative estimation of the speed of the spread of a potential head of the fire, the quantity of fuel, the intensity of burned fire (modeling and simulation of fire) allows the FBP (Forest Fire Behavior Prediction) system. It enables specification of the fire area, the fire perimeter, and fire behavior on the fire flank and fire back, applying an ellipse zoom model [12].

In the USA, for the information about the current and potential danger of fire serves an equivalent system to the Canadian system - the Wildland Fire Assessment System, WFAS called.

The European Commission, the Joint Research Centre Directorate (Directorate General Joint Research Centre) started in 2000 the European Forest Fire Risk Forecasting System (EFFRFS). At the beginning, this system was created as a joint platform for the implementation of selected of the European national fire danger indices resulting from the current state of the weather, for the purpose of drawing up the common reference for determination of the fire danger and also the promotion of cooperation between the national services during emergencies (fires) beyond the borders of the states. In 2001, the EFFRFS system became a part of the European Forest Fire Information System (EFFIS).

The system was created and launched by the Directorate of the Joint Research Centre and coordinated by the Directorate General for Environment (DG Environment) and is designed for end users, which are Civil Protection and the Forestry Service of the Member States. EFFIS is designed for the conditions before the fire and after the fire and is a support tool for the Member States of the European Union (EU) and the European Commission (EC) on the protection of forests against fire, in particular, in the form of georeferenced information. Currently, in the period of increased incidence of fires, EFFRFS offers 6 different meteorological indexes of danger on a daily basis, based on weather data. Consequently, there are produced and published maps of the EU, which represent the spatial distribution of the degree of fire risk with the forecast for the next three days.

In Slovakia, the role of the fire warning system fulfills a web portal operated by the Slovak Hydrometeorological Institute, which on a daily basis, from April to the end of September, each year, provides information on the meteorological fire index, which is based on the calculation of Baumgartner fire index.

With the analysis of the risk and its components in relation to the forest fires in the Slovak conditions engaged several authors. It should be noted that the methodologies produced are well accepted in the European research area.

The first methodological procedures concerning the analysis of the risk of fire, the analysis of potential damage of forest fires respectively, were published in 2003 in the framework of the WARM project the (project of the 5th Framework Program of E.U.), and the analysis has been carried out for the territory of the Slovensky raj National Park. Partial results were published in [13] and [14].

For the last time, the updated methodology was published in [15, 16].

The methodology used for risk assessment was developed on the basis of fire data on forest fires from the experimental area – Slovensky raj National Park, recorded in the last 20 years period. It is based on two types of analyses. In the first type, there is a risk of fire described in terms of probability, which corresponds to the expected damage to the forest, on the basis of its tree species composition and of age in a given year. In the second type of analysis, there is tested the effect of the fire on the relevant geographic factors (altitude, slope, exposure, the distance to the nearest road and the distance to the nearest settlement). This is done on the basis of a comparison of the frequency of values of analyzed factors on the areas destroyed by fire, and in whole extent of the experimental area.

From the perspective of spatial scale, this methodology is appropriate for its implementation into the GIS/spatially based systems. The spatial scale of the model is represented by a forest. The methodology is suitable not only for mono-cultural, but also for mixed stands. From the perspective of the time scale is suitable for tactical and

strategic planning of the operations in the forest.

In the paper is introduced a methodology for the assessment of the risk of fire based on the multicriterial assessment of individual factors, which have an impact on its occurrence or next propagation. This is based on automated processing through the decision-making model as part of a spatial decision support system.

IV. Spatial decision support systems

The term spatial decision support systems (SDSS) means a combination of a geographical information system (GIS) and analytical decision models to create a system with special abilities to cover the resolution of complex spatial problems. The intent is to support the creation of a decision using a quantitative approach based on the geographic information stored and manipulated in the GIS [17].

GIS provides a robust and unified framework for managing spatial data used in most planning, design and development activities. Additionally, GIS enable analysts to control simple and complex spatial analysis and transform data into visual information, primarily in the form of a map[17].

Despite these advantages, GIS is unable to be of use in supporting and resolving hardly defined decision problems characterized by the multiple criteria evaluation and multiple, often time conflicting, objectives [17].

SDSS as a spatial extension of a decision support systems involves computer systems used to support decision making in spatially oriented problems where it is impossible to use an automated system to resolve the entire decision making process. However, even difficult to comprehend factors may be considered using reference data and the decision maker who interactively uses such system, makes that choice [17].

SDSS provide a mechanism for entering spatial data, permit the representation of spatial relationships and structures, contain analytical techniques for spatial and geographic analysis and provide tools to output various forms of spatial data, including maps [17].

V. Material and methodology

In the analyses were applied following data and geodata: geographical vector layers representing the forest stands in the experimental area, geographical vector layer of forest types and soil types, geographical vector layer of forest road network; digital relief model with spatial resolution of 10 m, geographical vector layers of the Central Spatial Database representing the settlements, buildings outlines, water bodies, roads provided by the Topography Institute in Banska Bystrica; and touristic trials and recreation sites geographical vector layer provided by the Mountain Rescue System.

For data pre-processing the ArcGIS environment was used. In the NetWeaver environment was built an independent hierarchical network to automate the procedure of forest fire risk, susceptibility to fire respectively, assessment. The assessment process was carried out in EMDS (Ecosystem Management Decision Support) system, a spatial decision support system which was used in the form of extension to ArcGIS environment, which the visualization of assessment results was provided in.

The analysis was based on mutual assessment of two basic groups of factors: natural and social (Fig. 1).

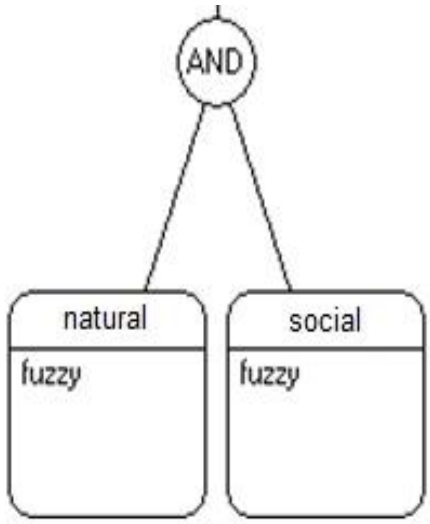

Fig. 1 Groups of factors entering the fire risk assessment

The group of natural factors consisted from the following sub-groups: factors of forest fuel (consisting of factor of fuel model and factor of fuel height), geographical factors (landform factor, slope and aspect factor), and forest stand factors (tree species composition factor, stand age factor and health condition factor). The social factors are represented by factors of the distance from nearest road, nearest settlement, identified forest fruit picking areas, management activities performed in forest during the 10 years period and identified tourist localities and structures.

To particular factors were assigned intervals and intervals of fuzzy values, as well as their weights, which they entered the evaluation process with (Table 1 - 4).

Table 1 Fuzzy values of particular classes of forest fuel factors group

Group	Factor	Class	Fuzzy value
Forest fuel (weight 1.0)	Fuel model	Without herbal cover	0.25
		Mosses and lichens	0.5
		Grasses, herbs and mosses	0.75
		Grasses	1.0
	Height of surface fuel	< 15 cm	0.25
		15 – 30 cm	0.6
		31 – 100 cm	1.0

Table 2 Fuzzy values of particular classes of geographical factors group

Group	Factor	Class	Fuzzy value
Geographical factors (weight 0.75)	Landform	Plane	1.0
		Valley	0.8
		Ridge	0.25
	Slope	0 – 45°	0.0 – 0.5
		> 46°	0.5 – 1.0
	Aspect	0 – 135 °	0.0 – 0.33
		136 – 180 °	0.33 – 1.0
		181 – 225 °	1.0 – 0.33
		226 – 360 °	0.33 – 0.0

Table 3 Fuzzy values of particular classes of forest stand factors group

Group	Factor	Class	Fuzzy value
Forest stand factors (weight 0.75)	Tree species composition	Deciduous	0.25
		Mixed	0.5
		Coniferous	1.0
	Stand age	0 – 20 years	0.0 – 1.0
		21 - 80 years	0.9 – 0.25
		> 81	0.25 – 0.5
	Health condition	Damaged by harmful agent	1.0
		Without	0.0

Table 4 Fuzzy values of particular classes of social factors group

Group	Factor	Class	Fuzzy value
Social factors (weight 1.0)	Distance from the nearest road	0 – 1 500 m	1.0 – 0.25
		> 1 501 m	0.25 – 0.0
	Distance from the nearest trail	0 – 50 m	1.0 – 0.25
		> 51 m	0.25 – 0.0
	Distance from the nearest settlement	0 – 3 000 m	1.0 – 0.25
		> 3 001 m	0.25 – 0.0
	Distance from the touristic and recreation sites	0 – 500 m	1.0 – 0.25
		> 501 m	0.25 – 0
	Fruit picking	With picking	1.0
		Without picking	0.0
	Harvesting and cultivation activities	With activity	1.0
		Without activity	0.0

VI. Results

Via interconnection of decision model with the EMDS analytical environment, which is available in the form of extension for ArcGIS Desktop environment, there was obtained a tool for automation of spatial analyses focusing the assessment of particular risk factors and their groups up to specification of associated susceptibility to fire.

The results of the analyses are introduced as in graphic as in tabular form.

First, there are introduced the results for associated susceptibility of the area to fire (Fig. 2). It was calculated as the sum of fuzzy values of natural and social groups of factors. The raster representing the spatial distribution of this sum values was repeatedly subjected to the process of fuzzification (process of raster values conversion applying the fuzzy logic principles). Consecutively, those new fuzzy values were extracted for centroids of each of the forest stand in the area.

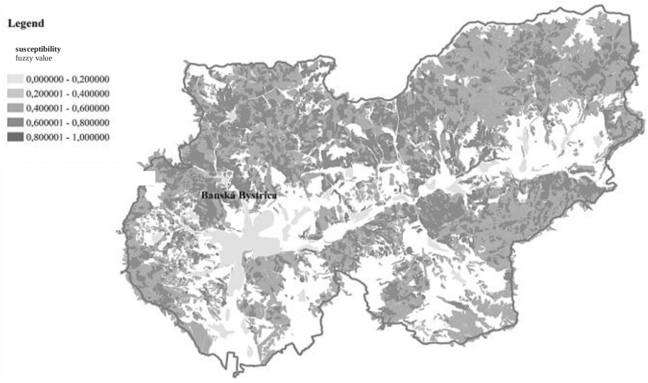

Fig. 2 Results of associated susceptibility to fire assessment

The results in tabular form are introduced In Table 5.

Table 5 Results of associated susceptibility to fire assessment

Fuzzy interval	Susceptibility degree	Extent	Representation
		[ha]	[%]
0.0 – 0.2	very low	1.03	0.002
0.2 – 0.4	low	700.43	1.286
0.4 – 0.6	medium high	33,041.4	60.648
0.6 – 0.8	high	2,0731.6	38.053
0.8 – 1.0	very high	6.28	0.012
minimum	0.000000		
maximum	0.819398		
Std.	0.088701		

Results showed that the most of the area (60%) belong to the medium high degree of susceptibility to fire and almost 40% of the area even to the high degree of susceptibility to fire.

In view of the forest fuel factors, there was ca. 75% of the area assigned to the very high degree of susceptibility to fire and 25% to the medium high degree (Fig. 3, Table 6). It is because the character of the area. The area is represented mostly by mountain terrain with mixed forest stands and rich grass and herbal cover of forest ground.

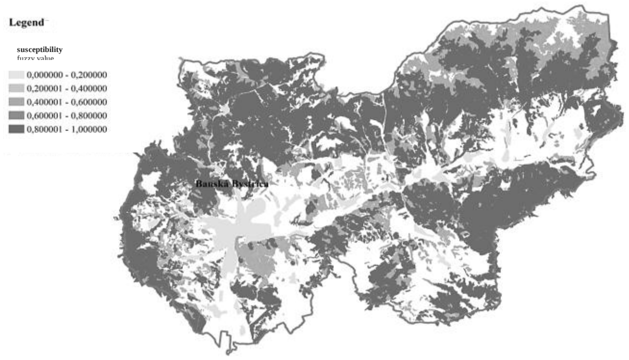

Fig. 3 Results of forest fuel factors assessment

Table 6 Results of forest fuel factors assessment

Fuzzy interval	Susceptibility degree	Extent	Representation
		[ha]	[%]
0.0 – 0.2	very low	0.65	0.001
0.2 – 0.4	low	106.73	0.196
0.4 – 0.6	medium high	13.00	24.585
0.6 – 0.8	high	0.00	0.000
0.8 – 1.0	very high	40.00	75.218
minimum	0.000000		
maximum	0.994386		
Std.	0.208021		

In view of the geographical factors (Table 7), almost the whole area was assigned to the highest degree of susceptibility to fire (94%). It is because the mountainous character of the area.

Table 7 Results of geographical factors assessment

Fuzzy interval	Susceptibility degree	Extent	Representation
		[ha]	[%]
0.0 – 0.2	very low	6.02	0.011
0.2 – 0.4	low	26.01	0.048
0.4 – 0.6	medium high	267.77	0.491
0.6 – 0.8	high	2,862.7	5.255
0.8 – 1.0	very high	51.00	94.195
minimum	0.000000		
maximum	1.000000		
Std.	0.129795		

Results of forest stand factors assessment (Table 8) showed that almost the whole area of the Slovenska Lupca forest management unit (84%) is situated in the lowest degree of susceptibility to fire that is because of the tree species composition and age of the forest stands, in particular. Higher degree of susceptibility of fire was found in stands that were affected by wind disaster disturbance and consequent infestation with bark beetle in the last ten years.

Table 8 Results of stand parameters assessment

Fuzzy interval	Susceptibility degree	Extent	Representation
		[ha]	[%]
0.0 – 0.2	very low	46.00	84.376
0.2 – 0.4	low	0.00	0.000
0.4 – 0.6	medium high	4,878.3	8.939
0.6 – 0.8	high	3,648.1	6.685
0.8 – 1.0	very high	0.00	0.000
minimum	0.000000		
maximum	0.666667		
Std.	0.210913		

According to the results of social factors assessment it can be stated that the most of the area is situated in the medium high degree of susceptibility to fire (Fig. 4, Table 9). The forests in the area are often visited by humans picking the forest fruits and mushrooms. The occurrence of humans in the forest is also connected with performance of forest management activities, in particular in stands affected with wind disaster disturbance and infestation with bark beetle.

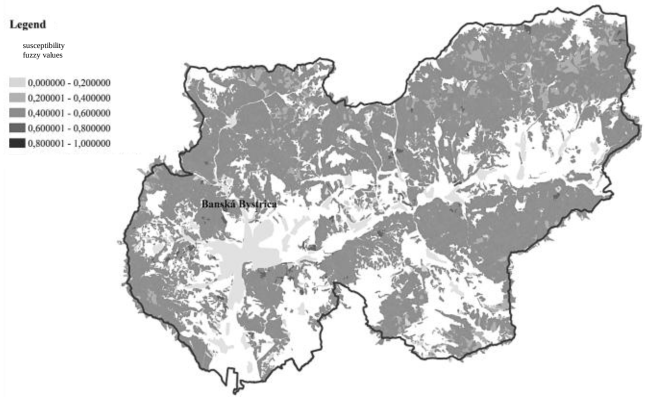

Fig. 4 Results of social factors assessment

Table 9 Results of social factors assessment

Fuzzy interval	Susceptibility degree	Extent	Representation
		[ha]	[%]
0.0 – 0.2	very low	1,420.12	2.607
0.2 – 0.4	low	3,664.02	6.725
0.4 – 0.6	medium high	48,901.0	89.758
0.6 – 0.8	high	495.58	0.910
0.8 – 1.0	very high	0.00	0.000
minimum	0.000000		
maximum	0.625000		
Std.	0.107083		

VII. Conclusions

Tackling the problem of forest fires, in particular their prevention is an important issue mostly in this period of

ongoing climate change. As it was mentioned the most important is the fire prevention. Knowing the fire danger or fire risk allows us to prepare for coping with fire in advance. From long-term planning point of view it allows to build strategies and realize efficient prevention measures as in social, economic as well as in environmental sphere.

Implementation of information system, GIS or expert systems is a logical outcome, because they provide decision makers with tools and function used to develop and enhance the methodologies and procedures taking into the consideration the spatial dimension of the problem tackled.

Here presented paper presents an approach to forest fire risk assessment in terms of the susceptibility of an area to fire.

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